INTERIM REPORT

SATELLITE RELIABILITY SPECTRUM

Contract SD-77, Advanced Research Projects Agency

July 27, 1961

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Advanced Research Projects Agency

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1. GENERAL BACKGROUND

This is a continuation of the study started in 1960 and reported by ARINC Research Corporation on September 30, 1960, under the title Progress Report on a Study of Satellites in Orbit. The initial work and the above-named report were accomplished under Advanced Research Projects Agency Contract IDA-50-3. The study contained the analysis of the Vanguard satellites I, II, and III, and the EXPLORER VI satellite. Each system was related by "operational life" to system complexity, where the unit of complexity measurement was an "active element group". The active element group is defined as a transistor or tube and its associated passive network. In these satellites, an active element group was normally composed of a transistor, a diode, three resistors and two capacitors.

The study under the present ARPA contract, SD-77, commenced in February 1961. The new contract calls for the establishment of a reliability spectrum for orbiting systems. There are three sub-areas in the work statement:

a) "Evaluate and monitor the reliability of the TIROS I and EXPLORER VII satellite electronic systems.

b) Evaluate and monitor the reliability of the electronic systems of COURIER, and up to five additional systems to be specified by ARPA and scheduled for orbiting during Fiscal Year 1961.

c) Using the data collected under this and previous contracts, establish the reliability spectrum of orbital electronic systems as a function of complexity."

The ARPA contract contained another major task, the periodic reliability reviews of MIDAS, SAMOS, TRANSIT, and ADVENT. Data from the TRANSIT satellite systems have been used in the spectrum study presented in this report.

1.1 Purpose of the Study

Effort was made to develop a

The ~~ultimate goal of this study is the development of the~~ satellite reliability spectrum using as input data the known complexity of each operational function in the satellite and the observed operational orbit hours to malfunction, failure,

or censoring. Each such observation will provide a point on the log-log scattergram of reliability versus complexity. From these points, a "least squares" regression line will be calculated, representing the middle of the satellite reliability spectrum. A distribution of observations at various complexities will be used to determine the width of the band about this line.

The satellite spectrum will be an important tool in the reliability assurance programs of all future satellites. By its use, the new satellite may be evaluated realistically in the predesign stage to determine the reliability-feasibility of the proposed new systems. The spectrum can be used as an aid in determining which trade-off should be accepted for ultimate system performance under any given specification. The designer may use the spectrum band as a guide in determining the degree of sophistication or simplicity he should use in various circuits to accomplish the assigned tasks. In other words, the satellite reliability spectrum will provide reliability prediction throughout the predesign, design, and prototype stages of new satellite development.

A secondary purpose of the program is to develop more realistic component part failure rates for in-orbit applications. The data available are mostly of the censored type in which the number of operational orbit hours to censoring is used to determine the lives of various types of component parts under space environment conditions. The failure rates which are presently used in the prediction of satellite reliability are based on data obtained from ground, shipborne, and airborne equipments, most of which utilized tubes rather than transistors. Multiplication factors (K factors) have been established to convert these observed data for use in transistorized equipments in the space environment.

The failure rates used for this study were derived in the report mentioned earlier.[*] All failure rates are assumed to remain constant over the period of time for which the prediction is made, and the effects of the deterioration phenomenon are not considered.

~~In this report, it will be noted~~ that the predicted time to first malfunction or failure is considerably more pessimistic than the observed time. This is an indication of the need for the revised component part failure rates which will

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[*] See "... Report ... a Study of Satellites in Orbit, dated September 30, 1961, by Aitel Research Corporation under Contract NrA-... .

be developed from this study. Better resolution of the K factors for evaluation of the in-orbit successes and failures of ground-controlled space vehicles is also required.

1.2 Assumptions

During the course of these evaluations and in the determination of mean time to failure (MTF), the following assumptions were made:

1) All part, AEG, or subsystem failure rates are constant.

2) The failure of the special sensory device does not cause the electronics of the function to fail.

3) Each function is independent of the other functions unless otherwise indicated.

4) A failure is incurred when the data received are not decodable or the operation required is not performed.

5) A malfunction may correct itself or may be corrected by commands from the ground station.

1.3 Method of Evaluation

The method of evaluation used in this study calls for the determination of operational functions. Each such function is a complete operation essentially independent of any other operational function within the satellite. An operational function begins with an input from a sensor or the receiver antenna, and ends with the completion of the operation at a storage device, transmitter antenna, or switching device. The electronic units of several subsystems may be included in a single operational function; also, the same electronic units may be used in more than one operational function. A simplified reliability block diagram for an operational function of the Explorer VII satellite is shown below.
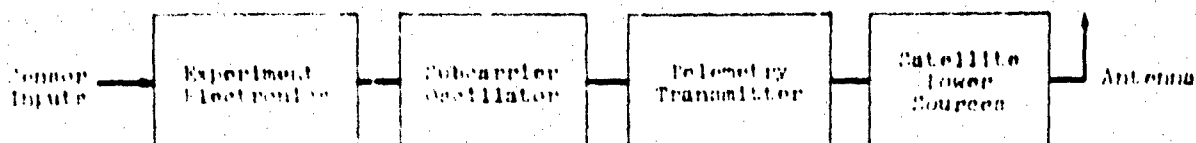
The operational functions for each satellite are enumerated in the separate evaluation sections in terms of operational orbit hours. Operational orbit hours are defined as the number of active circuit-use hours after successful launching of a satellite. The determination of this number is complicated by the following three modes of operational function employment:

1) Continuous operation, where the operational orbit hours and the in-orbit hours are the same.

2) Satellite-controlled time operation, in which a clock or timing device in the satellite automatically turns on and off certain electronic operational functions at scheduled time intervals.

3) Ground-controlled time operation, where a proper signal from the controlling ground station activates the operational function, and the loss of the signal automatically turns the function off.

The calculated or predicted times to malfunction are computed by two methods for most of these satellites. The first is the Part Failure Rate Method (PFRM), which involves analysis of the circuit and application of failure rates for each part. The exponential failure pattern is assumed in all instances. The second method involves the use of active element groups, and the computations are divided into two stress levels: Low (L), for parts used at less than 25 percent of rated electrical stress in an ambient temperature of 25°C or less; and Medium (M), for parts used at less than 50 percent of rating in ambient of 50°C or less. For the latter computation the space environment is assumed to be comparable to a well-controlled ground (fixed) operating environment, from the standpoint of its effect on part performance and reliability.

It can be seen that more detailed data are required to make a full evaluation of each operational function and the failure-free in-orbit hours of each part type. This additional information is being requested on the future satellite studies under this contract. It will permit greater accuracy in the spectrum-band determination and will supply much needed data on component-part behavior in space.

1.4 Reliability Spectrum

At this stage of development, no attempt will be made to fit a curve to the accumulated observed malfunction plots for the six satellite systems analyzed. Each system will have a plot of its reliability versus complexity showing

both the observed and the calculated or predicted data. A
line representing the upper limit of the shipborne spectrum
band will also be shown for comparative purposes. It will
be noted from the individual reliability-versus-complexity
plots that the calculated or predicted times to first mal-
functions appear to be pessimistic by nearly an order of
magnitude. This holds true for the average failure rates per
active element group also. The direct results of this find-
ing have led to further attempts on the part of ARINC Research
to reassess the component part failure rates as used in sat-
ellite reliability prediction.

Complexity is measured in active element groups, the
composition of which was stated earlier. Analysis has shown
that component parts that are not included in the active
element group are normally distributed at one per ten active
element groups. Where active redundancy exists, each oper-
ational path has been considered as an operational function.

1.5 Scope of Report

The scope of this interim report is limited to an analy-
sis of six satellite systems, whose performance was observed
through April 30, 1961. The six satellites analyzed in the
report are:

a) EXPLORER VII
b) TIROS I
c) TRANSIT IB
d) TRANSIT IIA
e) TRANSIT IIIB
f) COURIER IB

The analysis of each system includes a brief statement
of the system's design purpose and the latest available infor-
mation on orbital status; a discussion of the satellite con-
figuration and nature of the malfunctions reported, an evalu-
ation of the operational function, a table comparing the pre-
dicted or calculated time to malfunction and the data observed
in orbit, and a plot of reliability versus complexity for the
satellite.

2. RELIABILITY EVALUATION OF EXPLORER VII SATELLITE IN ORBIT

2.1 Purpose of EXPLORER VII

The EXPLORER VII satellite was designed solely for scientific purposes. Its 92.3-pound payload consisted of the eight experiments described below:

1) Heat radiation experiments to study the transfers of heat between the earth and the surrounding space.

2) Lyman-alpha and X-ray experiments to measure the spectral intensity of the Lyman-alpha line and X-ray radiation from the sun.

3) A solar aspect cell to determine the attitude of the satellite relative to the sun.

4) An ion chamber to measure intensity of three classes of heavy primary cosmic-ray particles.

5) An experiment to measure the intensity of primary and secondary cosmic radiation of the Van Allen belts over a period of time.

6) A solar-cell experiment to determine the effect of the spatial environment on the performance of exposed silicon solar cells.

7) Temperature measurements at five localized positions on the satellite.

8) A micrometeorite experiment to detect micrometeorite impacts of the order of 10 micron diameters.

2.2 Orbital Information and Status of EXPLORER VII

The EXPLORER VII was launched from the Atlantic Missile Range, Florida, on October 13, 1959. The orbit achieved has an apogee of 670.0 miles, a perigee of 343.6 miles, and a period of 101.1 minutes. The satellite was still transmitting telemetry information on the 20-megacycle transmitter after 13,560.0 hours in orbit.

The satellite electronic equipment suffered the first minor difficulty on October 28, 1959, approximately 360.0 orbit hours after launch, but the trouble cleared itself up by October 29th. Occasional subsequent difficulties were also experienced in the multiplexer, due possibly to the fact that high input voltages from the experiments caused the multiplexer to be biased. The limit at which the multiplexing networks operate is influenced by battery voltage; therefore, the trouble encountered appears most often while the satellite is in darkness and the batteries are not being charged. These minor difficulties have not been incorporated into the reliability-versus-complexity plot, primarily because the details of each trouble have not yet been received for use in this study.

Two malfunctions have occurred, both of which involved the multiplexer. Each was reflected in erratic operation, most probably due to low beta in one of the ring counter circuits. The first malfunction took place approximately 4440.0 hours after launch. The trouble corrected itself and the multiplexer channel worked properly in the daylight passes. On June 14, 1960, approximately 5880.0 orbit hours after launch, the multiplexer again malfunctioned. It resumed operation about 408 orbit hours later and was still operating on April 30, 1961.

2.3 Configuration of EXPLORER VII

The payload configuration is divided into two subsystems, each containing a transmitter and a power supply. One transmitter operated on 108 megacycles with 15-milliwatts of power output. It was powered by mercury batteries and had an expected life between four and six weeks in length. Battery failure took place after 1238 hours of operation. No attempt was made to keep this transmitter operating beyond the battery life, as there was no provision for recharging the batteries.

The second transmitter telemeters seven out of the eight experiments. It has an output of one watt and is powered by both solar cell arrays and nickel-cadmium batteries.

2.4 Evaluation of EXPLORER VII

For the purposes of this evaluation, the satellite is divided into five operational functions:

1) 108-Megacycle Telemetry/Tracking Function
2) RIAS Heavy Primary Particle Function

3) Thermal Radiation Balance Function
4) Cosmic Ray Function
5) Lyman Alpha and X-ray Function

Table 1 presents for each of these functions, the number of active element groups, the calculated or predicted time to malfunction, the observed times of malfunctions, and the orbit hours of operation until censoring of the data, where applicable. The calculated or predicted values and the observed or censored values are plotted against the active-element-group complexity of the operational functions in Figure 1.

The monitoring of this satellite will continue until failure or the end of this contract, whichever occurs first. The results of any further observations will be presented in the final report.

TABLE 1

EXPLORER VII: CALCULATED AND OBSERVED DATA

Material/Active Element in use	Calculated Time to Malfunction (Hrs.)			Orbit Hours to Function Failure	Orbit Hours to 1st Malfunction	Orbit Hours to 2nd Malfunction	Orbit Hours to Censoring
	PFRM*	AEG (L)**	AEG (M)+				
...	3555.0	5595.0	3555.5				1238.0
...	721.9	493.0	374.3	Not Observed	4440.0	5880.0	13560.0
...	1120.4	803.7	554.1				13560.0
...	797.5	1201.0	956.1				13560.0
...	1071.9	1277.3	664.3			5880.0	13560.0

* PFRM - Part Failure Rate Model

** AEG (L) - Active Element Group computation at low stress level (L)

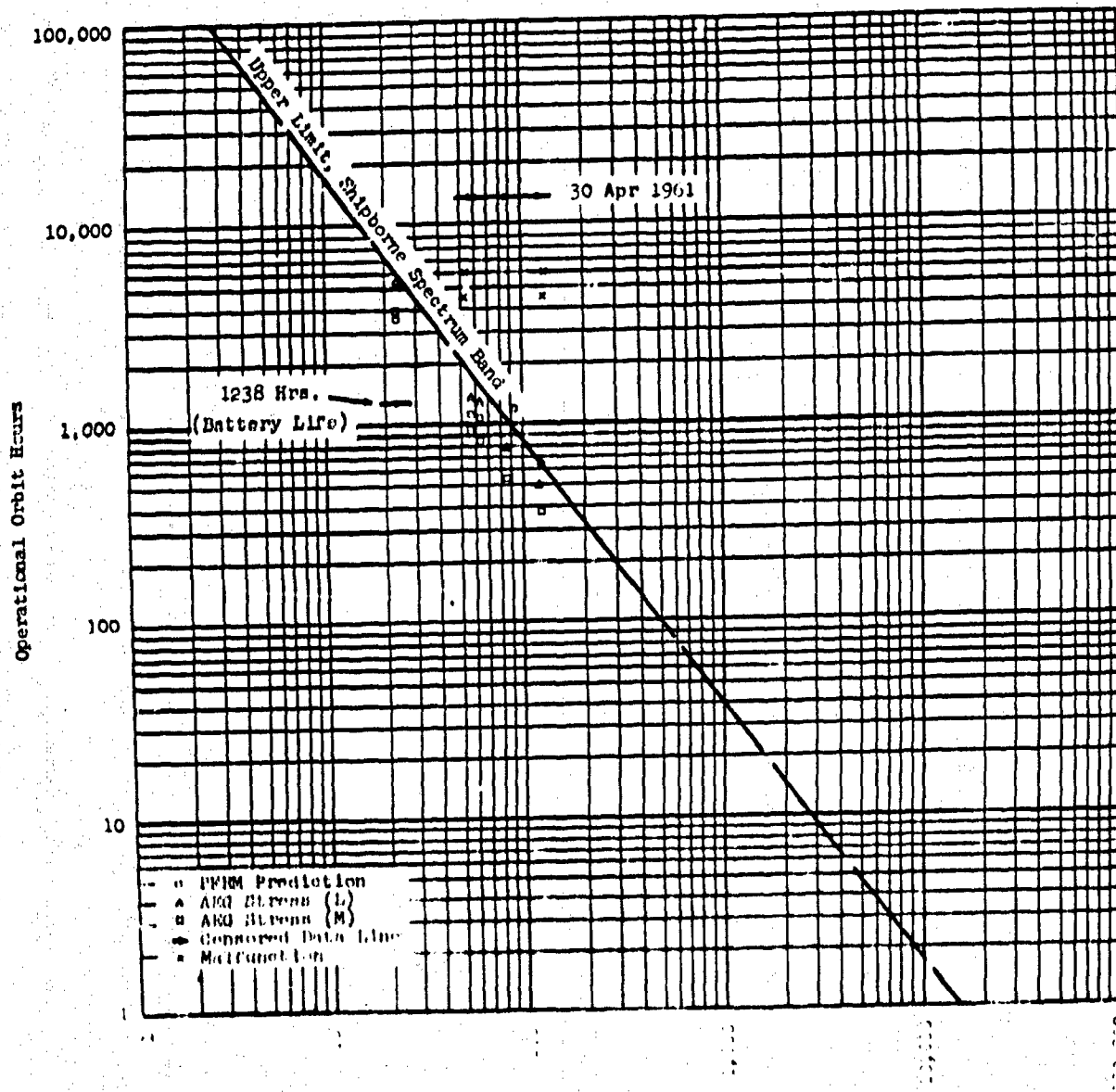+ AEG (M) - Active Element Group computation at medium stress level (M)

FIGURE 1

EXPLORER VIII PREDICTED AND OBSERVED RELIABILITY vs. COMPLEXITY

3. RELIABILITY EVALUATION OF TIROS I SATELLITE IN ORBIT

3.1 Purpose of TIROS I

The TIROS I is an exploratory meteorological satellite conceived as an experimental vehicle for probing the feasibility of observing and telecommunicating to earth the cloud-cover and electromagnetic (or infra-red) radiations by means of an earth satellite. Only the cloud-cover portion of the project has been carried out by the TIROS I.

3.2 Orbital Information and Status of TIROS I

The TIROS I satellite was launched from the Atlantic Missile Range, Florida, on April 1, 1960. The orbit achieved has an apogee of 467.1 miles, a perigee of 428.9 miles, and a period of 99.1 minutes. The decision to discontinue attempts to interrogate TIROS I was made after orbit 1302 over Ft. Monmouth about midnight of June 29, 1960. At the time of this decision, the wide-angle camera and all the telemetry were inoperative. The 108.0-megacycle tracking beacon continues to operate.

The following malfunctions have occurred in the TIROS I:

1) After 36.3 hours in orbit, the remote capability of the narrow-angle camera was lost. The malfunction was corrected by electrical shock accidentally after 944.8 orbit hours. The trouble was apparently caused by a mechanical failure in the clock subsystem. A similar malfunction occurred when the spin-up rockets were fired on May 27th. This was corrected by the same electrical shock method that was discovered earlier. The narrow-angle camera and its circuitry were still operable when the decision to cease interrogation was made.

2) No difficulties were experienced with the wide-angle camera system or the telemetry until 1872 orbit hours, at which time it is believed that a relay became inoperative. The malfunction made it impossible for the camera to be turned off. This apparently drained the batteries and eventually caused the wide-angle camera transmitter to burn out. This damage appears to have affected the entire satellite system.

3.3 Configuration of TIROS I

The satellite has a total of 9260 solar cells forming the primary electrical source, and consists of eight subsystems as follows:

1) The TV Picture Subsystem
2) The Telemetry and Tracking Subsystem
3) The Satellite Function-Control Subsystem
4) The Satellite Position Indicator Subsystem
5) The Satellite Dynamics Control Subsystem
6) The Electrical Power Subsystem
7) The Antenna Subsystem
8) The Satellite Structure

3.4 Evaluation of TIROS I

There are 16 operational functions in the TIROS I satellite. These functions include four each for the narrow-angle and wide-angle camera operations and two each for Telemetry, Beacon Killer Command, Spin-up Rockets Command and Beacon Operation. The sixteen functions are enumerated below:

1) Narrow-Angle Direct Camera Operation
2) Wide-Angle Direct Camera Operation
3) Narrow-Angle Clock Set Operation
4) Wide-Angle Clock Set Operation
5) Narrow-Angle Remote Camera Operation
6) Wide-Angle Remote Camera Operation
7) Narrow-Angle Playback Operation
8) Wide-Angle Playback Operation
9) Telemetry Operation System #1
10) Telemetry Operation System #2
11) Beacon Killer Commands System #1
12) Beacon Killer Commands System #2
13) Spin-Up Rocket Command System #1
14) Spin-Up Rocket Command System #2
15) Beacon #1
16) Beacon #2

Not all electronic units are included in the present operational function designations, as certain schematic diagrams have not yet been made available to ARINC Research Corporation for analysis. When the schematics are received, appropriate adjustments will be made in both the calculated times to failure and the complexity numbers of the function to which the schematics apply. Based on the information available at this time, the calculated times to failure, the

number of active element groups, and the observed malfunctions
for each operational function are shown in Table 2. A plot
of the reliability (calculated and observed) versus the
current estimated complexity is presented in Figure 2.

TABLE 2

TIROS I: CALCULATED AND OBSERVED DATA

Operational Position	Number of Active Element Groups*	Calculated Times to Malfunction (hrs.)			Orbit Hours to Functional Failure	Orbit Hours to 1st Malfunction	Orbit Hours to 2nd Malfunction	Orbit Hours to Censoring
		PFRM	AEG (L)	AEG (M)				
(1) Narrow-Angle - Direct Camera	224	163.3	216.4	150.0	.			2136
(2) Wide-Angle - Direct Camera	224	163.3	216.4	150.0	1872			
(3) Narrow-Angle - Clock Set	278	269.7	297.8	206.8				2136
(4) Wide-Angle - Clock Set	278	269.7	297.8	206.8	1872			
(5) Narrow-Angle - Remote Camera	201	208.9	250.5	174.7		36.3		1227†
(6) Wide-Angle - Remote Camera	201	208.9	250.5	174.7	1872			
(7) Narrow-Angle - Playback	60	335.4	1350.3	937.7			Not Observed	1227†
(8) Wide-Angle - Playback	60	335.4	1350.3	937.7	1872			
(9) Telemetry - System #1	43	758.7	3474.6	2276.3	1872			2136
(10) Telemetry - System #2	43	758.7	3474.6	2276.3	1872			2136
(11) Beacon Killers - System #1	35	887.2	4115.9	2681.7				
(12) Beacon Killers - System #2	35	887.2	4115.9	2681.7				
(13) Spin-Up Rocket Command - System #1	33	945.3	4393.7	2858.0				9480
(14) Spin-Up Rocket Command - System #2	33	945.3	4393.7	2858.0				9480
(15) Beacon #1	23	1172.3	5938.2	3932.4				9480**
(16) Beacon #2	23	1172.3	5938.2	3932.4				9480**

* Some changes in the operational-functional complexity are expected when all schematics are fully analyzed.

** Beacons were still in operation on April 30, 1961.

† A period of 908.5 orbit hours was censored because of the malfunction in the clock for the narrow-angle camera, remote operations.
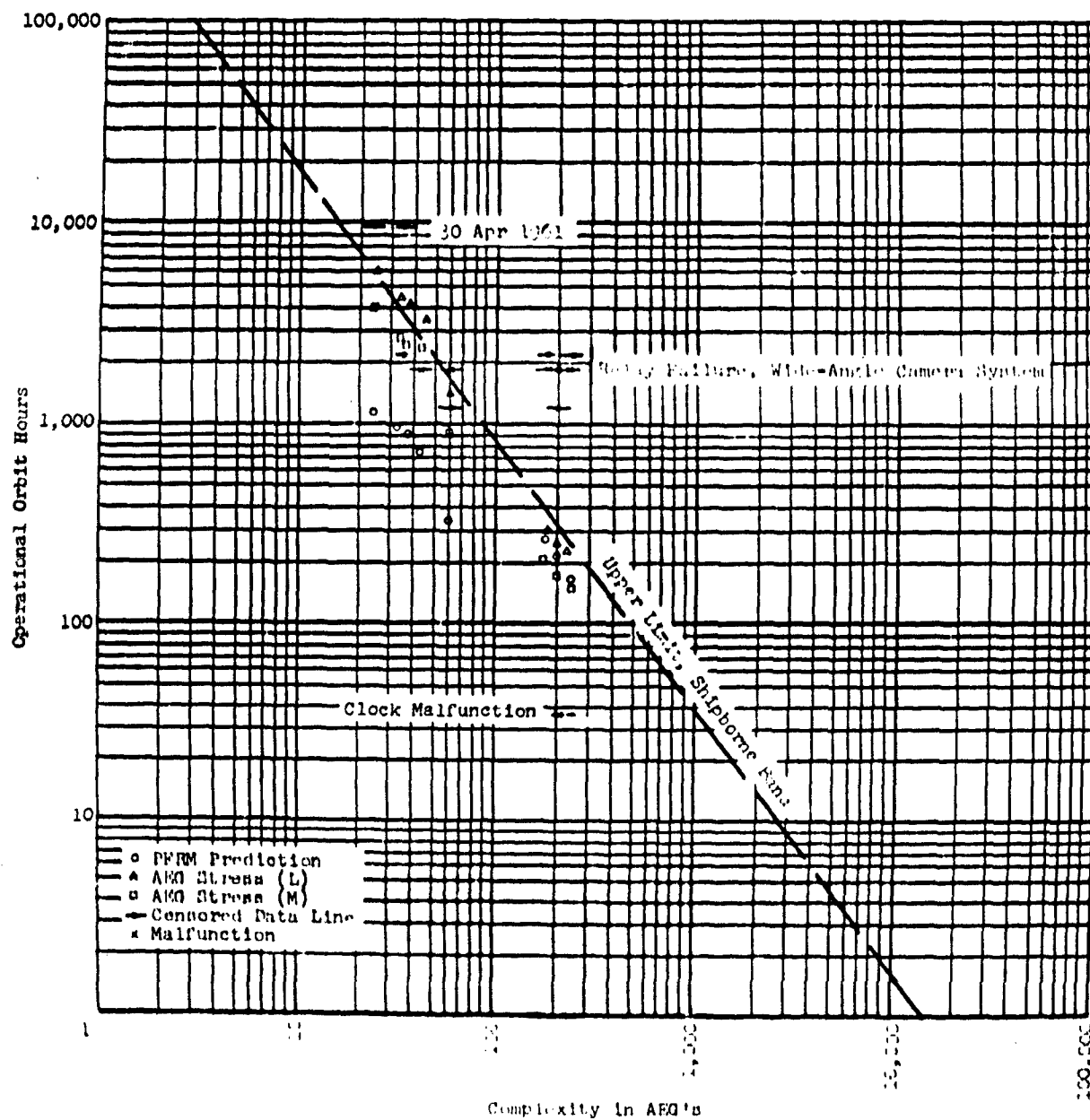
Operational Orbit Hours

Complexity in AEG's

FIGURE

FIROS I: CALCULATED AND OBSERVED RELIABILITY VS. COMPLEXITY

4. RELIABILITY EVALUATION OF TRANSIT SATELLITE SERIES IN ORBIT

4.1 Purpose of TRANSIT

The TRANSIT program calls for development of a system composed of approximately four circumterrestrial satellites and a network of ground control and tracking stations which can be used as· an aid to maritime navigation. The system of satellites in orbit will transmit doppler radio signals which can be utilized to make an accurate determination of the recipient's geographic location.

Each of the three successfully launched TRANSIT Satellites will be discussed separately.

4.2 TRANSIT IB

4.2.1 Orbital Information and Status of TRANSIT IB

The TRANSIT IB Satellite was launched from the Atlantic Missile Range, Florida, on April 13, 1960. It achieved an orbit with a period of 95.2 minutes, an apogee of 426.1 miles, and a perigee of 231.3 miles. This satellite malfunctioned at 2136 orbit hours, due to the opening of the thermal charging-limiter switch. The satellite was in operation Mode c when the failure occurred and, therefore, power was not available to shift to Mode b, which would have involved bypassing of the thermal charging-limiter switch.*

4.2.2 Configuration of TRANSIT IB

The TRANSIT IB is made up of several subsystems as described below.

1) Power Subsystem - This subsystem contains a primary battery supply, a silver-zinc battery with a life of 55 ± 10 days, a secondary nickel-cadmium battery which is rechargeable,

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* The modes are discussed in Section 4.2.2.

and the solar cell banks used to accomplish this recharging. A thermal switch is provided to protect the nickel-cadmium batteries from damage due to overheating during the recharge cycles.

2) Command Subsystem - This subsystem consists of two command receivers, an antenna system, and a switching device to change the satellite mode of operation. The transition from one mode to another requires either or both of the command receivers to operate, depending on the change desired.

3) Telemetry Subsystem - This subsystem is continuously energized by the solar secondary-battery power supply and pulse-modulates the 162-megacycle channel of the "B" doppler tracking transmitter.

4) "B" Doppler Tracking Subsystem - This subsystem is powered by the solar secondary power supply and is in active redundancy with the "C" doppler tracking subsystem.

5) "C" Doppler Tracking Subsystem - This subsystem is powered either by the silver-zinc battery or by the solar secondary-battery power.

The satellite has four possible modes of operation:

Mode a - Doppler "B" (and telemetry) transmitter on solar secondary-battery power. Doppler "C" transmitter on chemical primary-battery power.

Mode b - Power, same as Mode a. Secondary-battery thermal charge-limiter bypassed.

Mode c - Both doppler (and telemetry) transmitters on solar secondary-battery power.

Mode d - Doppler "B" (and telemetry) transmitter off. Doppler "C" transmitter on chemical primary-battery power. Secondary-battery thermal charge-limiter bypassed.

4.2.3 Evaluation

The delineation of the operational functions for the TRANSIT IB requires consideration of each mode of operation listed above. The differences between the modes are matters of the alignment of the operational functions with the various power sources and the position of the switch on the thermal charging-limiter. There are three major operational functions:

1) Telemetry Function
2) Doppler "B" Function
3) Doppler "C" Function

The electronic operations, including power sources, are identical under the following conditions:

1) Modes a and c - the Telemetry Function
2) Modes a and c - the Doppler "B" Function
3) Modes a, b, and d - the Doppler "C" Function

Table 3 presents for each operational function the ARINC Research Corporation predictions from the TRANSIT reliability evaluation of May 1, 1960,* and the observed time of failure as discussed in Section 4.2.1. Figure 3 is the reliability-versus-complexity plot for the data contained in Table 3.

4.3 TRANSIT IIA

4.3.1 Orbital Information and Status of TRANSIT IIA

This satellite was launched from the Atlantic Missile Range, Florida, on June 22, 1960. It achieved an orbit with a period of 101.6 minutes, an apogee of 649.7 miles, and a perigee of 389.2 miles.

As of April 30, 1961, this satellite was still transmitting. However, some malfunctions had been observed. These included (a) a change in frequency of one command receiver during the first 48 hours in orbit, and stabilization at the new frequency; and (b) loss of the final power-amplifier section in the telemetry transmitter on September 17, 1960, when signals were lost in background noise. This transmitter was recorded for 15 seconds on May 5, 1961, but the signal strength was very low.

The failure of the thermal switch in TRANSIT IB caused the decision to be made to shift TRANSIT IIA to operational Mode c, where the thermal switch bypass is closed. This prevented the thermal switch from disabling the circuits. The decision placed a continuous 600-milliampere load on the power subsystem. When the satellite commenced passes through

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* ARINC Research Corporation, A Preliminary Evaluation of TRANSIT Reliability, May 1, 1960.

TABLE 3

TRANSIT IB: PREDICTED, CALCULATED, AND OBSERVED DATA

Critical Function	Number of Active Element Groups	Predicted Hours to Failure*	Calculated Hours to Malfunction		Orbit Hours to Functional Failure	Orbit Hours to 1st Malfunction	Orbit Hours to 2nd Malfunction	Orbit Hours to Censoring**
			AEG (L)	AEG (M)				
(1) Command Function	20	3020	6218.9	4317.8				2136
(2) Telemetry Function - Mode a or c	45	5660	2014.0	1498.8				2136
(3) Telemetry Function - Mode b	45	5660	2014.0	1498.8				2136
(4) Doppler "B" Function - Mode a or b	37	2155	2644.1	1836.2	Not Observed	Not Observed	Not Observed	2136
(5) Doppler "B" Function - Mode b	37	2155	2644.1	1836.2				2136
(6) Doppler "C" Function - Mode a, b, d	33	1320†	3099.8	2152.4				2136
(7) Doppler "C" Function - Mode b	33	2247	3099.8	2152.4				2136

* Predicted data from ARINC Research Corporation report dated May 1, 1960.

** Censoring of all electronic equipment caused by failure at the thermal charging-limiter switch.

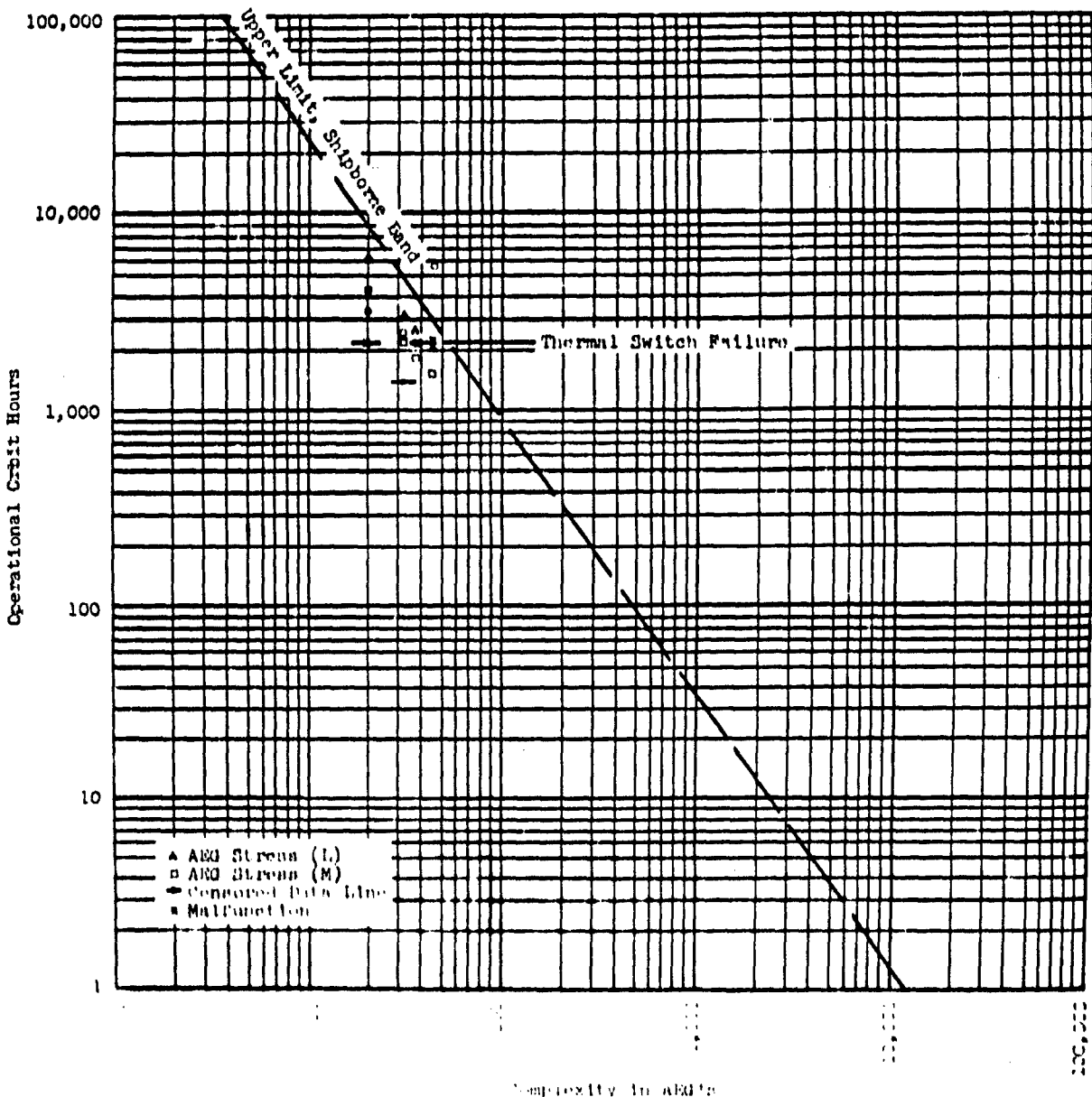† Calculated life of silver-zinc Battery Power Supply.

Complexity in AEG's

FIGURE

TRANSIT PREDICTED AND OBSERVED RELIABILITY VS. COMPLEXITY

the earth's shadow, the load depleted the battery before re-
entry into the sunlight, and the period of sunlight was
not sufficient to fully recharge the nickel-cadmium batteries.
The effects of this deep cycling were shown after November 15,
as the satellite became inoperative each time upon entering
the earth's shadow. This action continued with all subsystems
in operation until February 22, 1961. Thereafter, available
power was sufficient only to operate the Doppler "B" system.
It is theorized that the batteries shorted, thus increasing
the load across the solar power section until a failure took
place in one or more solar arrays.

4.3.2 Configuration of TRANSIT IIA

There are five basic subsystems in the TRANSIT IIA:

1) Power Subsystem - The power subsystem consists of
(a) 3600 solar cells, arranged in 24 paths of 50 cells with
a blocking diode, and (b) 12 F-type nickel-cadmium cells as
the rechargeable-battery power source for shadow-pass oper-
ation. This subsystem also contains the thermal charging-
limiter switch and a DC/DC battery voltage regulator.

2) Command Subsystem - The command subsystem is made up
of two command receivers, a DC/DC converter, and a mode-
switching device.

3) Antenna Subsystem - The antenna subsystem consists
of a spherical spiral antenna and the antenna coupling net-
work.

4) Telemetry Subsystem - The telemetry subsystem con-
sists of a 108.6-megacycle phase-modulated transmitter, four
subcarrier oscillators, a voltage regulator, a pulse-time
division multiplexer, and a DC/DC converter. In addition,
the multiplexer may receive a timing input from a digital
clock, which is supplied with a 3-megacycle signal from the
3-megacycle oscillator of the "B" Doppler system. The clock
receives its power from a separate DC/DC converter.

5) Doppler Subsystems - The doppler subsystems, "B" and
"C", are in active redundancy. Each subsystem contains a
DC/DC converter, a 3-megacycle oscillator, a frequency multi-
plier and two transmitter power amplifiers in active redun-
dancy.

The satellite has four modes of operation:

Mode a - All electronic equipment in use and the thermal
charging-limiter-switch bypass open.

Mode b - Same as Mode a except that the telemetry sub-system, less the digital clock, has been turned off.

Mode c - Same as Mode a except that the thermal charging-limiter-switch bypass is closed, thus removing this switch from the necessary circuitry.

Mode d - The satellite "off" mode, in which the thermal charging-limiter-switch bypass is open and all electronic subsystems except the command subsystem are off.

4.3.3 Evaluation of TRANSIT IIA

In the delineation of the operational functions of this satellite, it was necessary to consider each mode of operation and its effects on the electronics of the functions. There are nine operational functions in the TRANSIT IIA:

1) Command Function
2) Telemetry Function in Mode a operation
3) Telemetry Function in Mode c operation
4) Telemetry with Digital Clock Function in Mode a operation
5) Telemetry with Digital Clock Function in Mode c operation
6) Doppler "B" System Function in Mode a or b operation
7) Doppler "B" System Function in Mode c operation
8) Doppler "C" System Function in Mode a or b operation
9) Doppler "C" System Function in Mode c operation

Presented in Table 4 are ARINC Research Corporation's predicted values for the operational functions as derived from the data in the report entitled A Preliminary Evaluation of TRANSIT Reliability, dated May 1, 1960. Also presented is the calculated time to malfunction by the active-element-group method at both low and medium part-stress levels. Figure 4 is the reliability-versus-complexity plot for the TRANSIT IIA satellite.

4.4 TRANSIT IIIB

4.4.1 Orbital Information and Status of TRANSIT IIIB

The TRANSIT IIIB Satellite was launched from the Atlantic Missile Range, Florida, on February 21, 1961. The orbit achieved was low, and the TRANSIT IIIB did not separate from either the "piggy-back" satellite, LOFTI, or the Fourth Stage Vehicle. The orbit had an apogee of 429 miles, a

TABLE 4

TRANSIT IIA: PREDICTED, CALCULATED, AND OBSERVED DATA

Functional Function	Number of Active Element Groups	Predicted Hours to Failure*	Calculated Hours to Malfunction AEG (L)	AEG (M)	Orbit Hours to Functional Failure	Orbit Hours to 1st Malfunction	Orbit Hours to 2nd Malfunction	Orbit Hours to Censoring
(1) Command Function	28	3080	3896	2703.		48		7248
(2) Telemetry Function - Mode a	77	4790	750	526.3				
(3) Telemetry Function - Mode b	77	4790	750	526.3	Not Observed	2088		
(4) Telemetry with Digital Clock - Mode a	95		566	393.0				
(5) Telemetry with Digital Clock - Mode b	95		566	393.0		2088		
(6) Doppler "B" Function - Mode a or b	33	2412	3100	2153.				
(7) Doppler "B" Function - Mode a or b	33	2412	3100	2153.		3504		
(8) Doppler "C" Function - Mode a or b	23	2412	5121	3554				
(9) Doppler "C" Function - Mode b	23	2412	5121	3554		3504	5880	

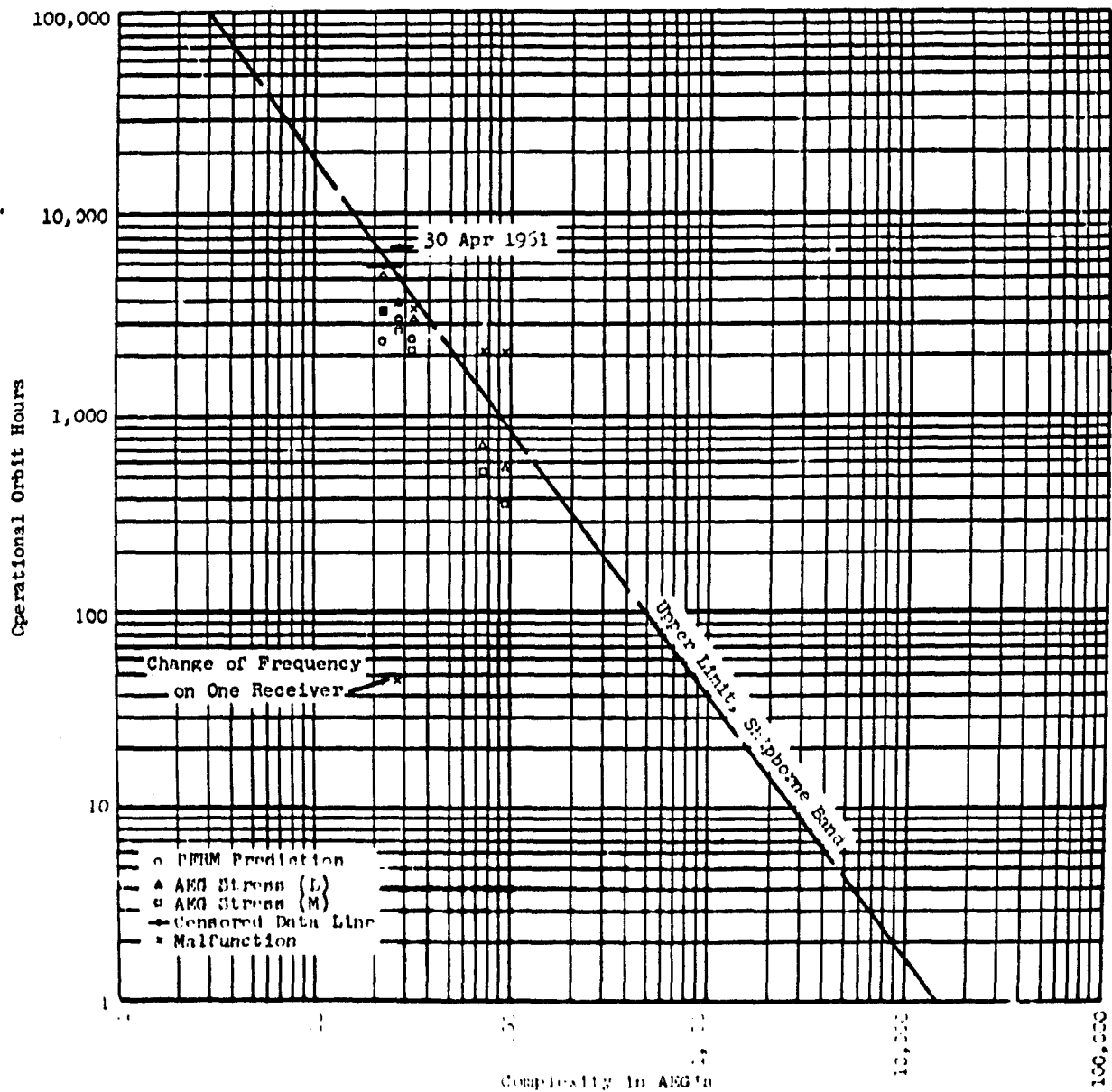* Predicted data from ARINC Research Corporation report dated May 1, 1960.

FIGURE 4

TRANSIT IIA: CALCULATED AND OBSERVED RELIABILITY VS. COMPLEXITY

perigee of 117 miles, and a period of 93.2 minutes. The
TRANSIT IIIB Satellite returned to earth and was destroyed on
March 30, 1961.

The orbital life of the satellite was approximately
912 hours. Immediately after launch, the telemetry informa-
tion from the Automatic Gain Control showed that one of the
command receivers was inoperative. It has been theorized
that a transistor may have failed in this receiver.

4.4.2 Configuration of TRANSIT IIIB

The general configuration of the TRANSIT IIIB may be
divided into six basic subsystems:

1) Antenna Subsystem - This subsystem contains the
spherical spiral antenna and the antenna coupling network.

2) Command Subsystem - The command subsystem consists
of two command receivers, each with a master timing gate, a
command gate, and a memory gate. The subsystem also contains
an output amplifier, a voltage regulator for solar power-
input sources, and main and auxiliary battery power supplies.

3) Power Subsystem - The power subsystem is made up of
the solar cell arrays, main and auxiliary nickel-cadmium
batteries, a main-battery override switch, a main-battery
voltage-sensing switch, an auxiliary battery voltage-sensing
switch, a Zener diode path, a voltage-regulator bypass switch,
and a voltage regulator. The subsystem has three separate
power sources and four paths to provide power at the voltage-
regulator bypass switch. This switch then provides two
alternative paths to the electrical bus.

4) Telemetry Subsystem - The telemetry subsystem is
divided into five sensor input groups. Three groups supply
inputs to the 5.0-kilocycle, 3.0-kilocycle, and 2.3-kilocycle
subcarrier oscillators, and the remaining two groups supply
information to the 10.5-kilocycle subcarrier oscillator.
The telemetry from the memory subsystem is impressed on the
10.5-kilocycle subcarrier along with the PDM encoder output
from the thermistors. The units of this subsystem are the
PDM encoder; the 10.5-, 5.0-, 3.0-, and 2.3-kilocycle sub-
carrier oscillators; a calibration injector and relay; a
voltage regulator; a telemetry transmitter; a DC/DC converter
EM 872-3; and a telemetry command switch.

5) Doppler Subsystem - The doppler subsystem consists
of two oscillators, an oscillator switch, a B+E switch, two
DC/DC converters EM 872-1, two 54-megacycle multipliers, and
four transmitters operating, respectively, at 54, 162, 216 and

324 megacycles. In order to utilize the doppler subsystem, one oscillator and two transmitters, plus the various electronic units between them, must work.

4.4.3 Evaluation of TRANSIT IIIB

The delineation of the operational functions of the TRANSIT IIIB requires consideration, first, of the various power sources which operate the electronic equipment; next, of the functions by type; and finally of the combined functional operations. There are 11 major operational functions, 2 of which have 5 sub-functions each. The operational functions are listed below:

1) Command Function

2) Telemetry Function - Solar Power

      a) Thermistor and PDM Encoder
      b) Memory Telemetry
      c) 5.0 kc Sensor Inputs
      d) 3.0 kc Sensor Inputs
      e) 2.3 kc Sensor Inputs

3) Telemetry Function - Battery Power

      a) Thermistor and PDM Encoder
      b) Memory Telemetry
      c) 5.0 kc Sensor Inputs
      d) 3.0 kc Sensor Inputs
      e) 2.3 kc Sensor Inputs

4) Doppler Function, System A, Solar Power

5) Doppler Function, System A, Battery Power

6) Doppler Function, System B, Solar Power

7) Doppler Function, System B, Battery Power

8) Operational Function, System A, Solar Power

9) Operational Function, System A, Battery Power

10) Operational Function, System B, Solar Power

11) Operational Function, System B, Battery Power

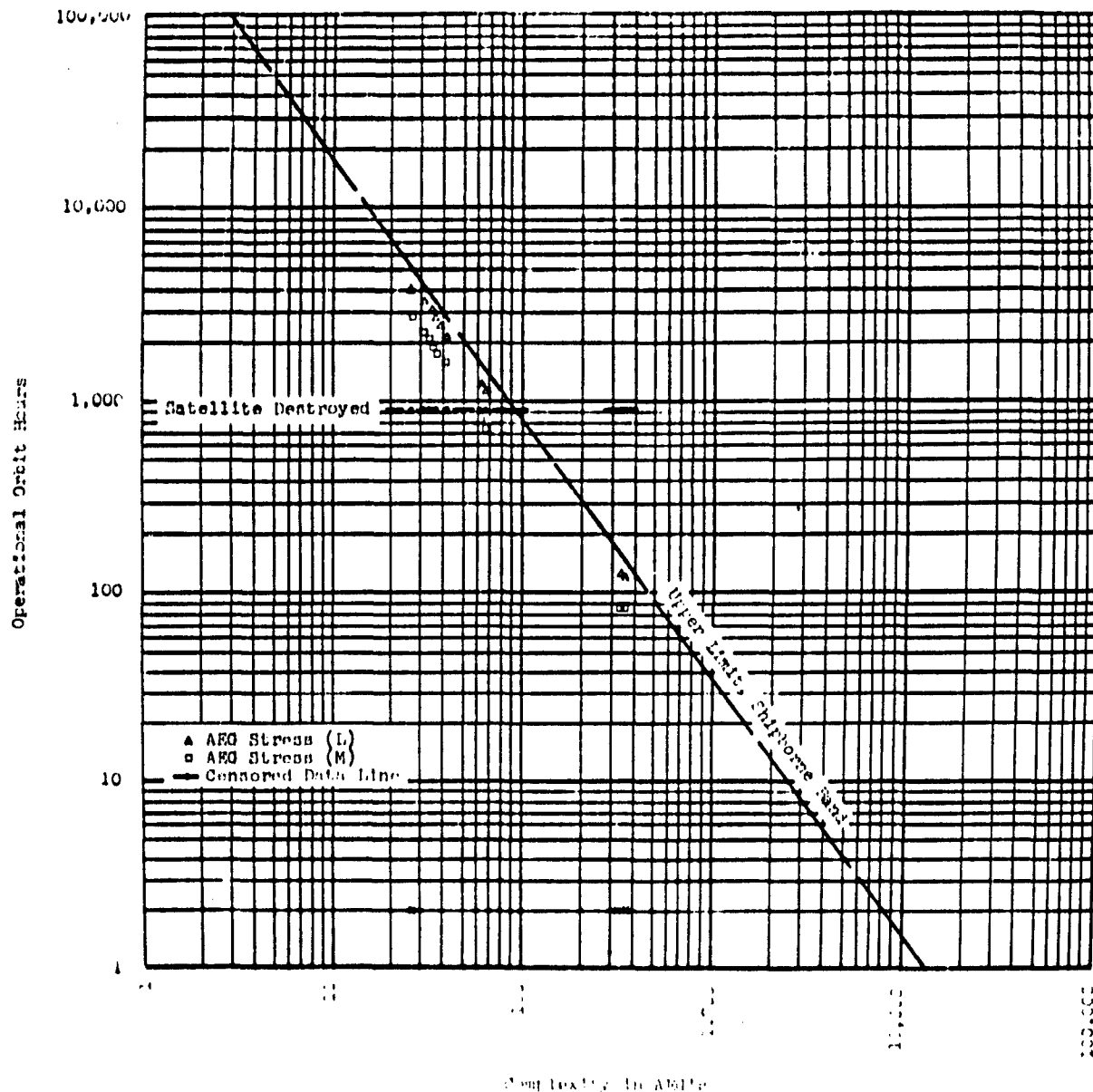The predicted values given in Table 5 were derived from the data in ARINC Research Corporation's third report on TRANSIT reliability, dated May 5, 1961. The calculated time to malfunction by the active-element-group method for low and medium stress levels, and the time of data censoring due to the poor orbit are also included in the table. The reliability-versus-complexity plot for the TRANSIT IIIB is shown in Figure 5.

TABLE 5

TRANSIT IIIB: PREDICTED, CALCULATED AND OBSERVED DATA

Operational Function	Number of Active Element Groups	Predicted Hours to Failure*	Calculated Hours to Malfunction AEG (L)	Calculated Hours to Malfunction AEG (M)	Orbit Hours to Functional Failure	Orbit Hours to 1st Malfunction	Orbit Hours to 2nd Malfunction	Orbit Hours to Censoring
(1) Command Function	27		4098	2911	2			912
(2) Telemetry Function - Solar Power	65	1050	1208	839				912
a) Thermistors and PCM Encoder	33		3100	2153				
b) Memory Telemetry	37		2642	1836				
c) 5.0 kc Sensor Inputs	37		2642	1836				
d) 3.0 kc Sensor Inputs	37		2642	1836				
e) 2.3 kc Sensor Inputs	37		2642	1836				
(3) Telemetry Function - Battery Power	19	1050	1112	773				912
a) Thermistors and PCM Encoder	37		2642	1836				
b) Memory Telemetry	41		2292	1591				
c) 5.0 kc Sensor Inputs	41		2292	1591				
d) 3.0 kc Sensor Inputs	41		2292	1591				
e) 2.3 kc Sensor Inputs	41		2292	1591				
(4) Doppler Function "A" - Solar Power	33	2150	3100	2153				912
(5) Doppler Function "A" - Battery	37	2150	2642	1836				912
(6) Doppler Function "B" - Solar Power	31	2150	3381	2347				912
(7) Doppler Function "B" - Battery	35	2150	2857	1984				912
(8) Operational Function "A" - Solar	337	150	122.5	86.0		2		912
(9) Operational Function "A" - Battery	341	150	121.8	84.0		2		912
(10) Operational Function "B" - Solar	335	150	122.5	85.8		2		912
(11) Operational Function "B" - Battery	339	150	121.5	84.4		2		912

(Orbit Hours to 2nd Malfunction column: Not Observed)

* Predicted data from ARINC Research Corporation report dated May 5, 1961.

Figure 5.

TRANSIT IIIBI CALCULATED AND OBSERVED RELIABILITY VS. COMPLEXITY

5. RELIABILITY EVALUATION OF COURIER IB SATELLITE IN ORBIT

5.1 Purpose of COURIER IB

The COURIER satellite is an active communication satellite having both a real-time relay action and a delayed-time relay action. Real-time relaying is accomplished when both the transmitting and the receiving ground station simultaneously are actively controlling the satellite. The satellite receives the message and simultaneously retransmits it. The delayed time action occurs when only one ground station is in control of the satellite. In this case, the satellite receives the message-and-address group and stores it on a magnetic tape until the proper ground station interrogates the satellite and then retransmits the message.

5.2 Orbital Information and Status of COURIER IB

The COURIER IB Satellite was launched from the Atlantic Missile Range, Florida, on October 4, 1960. The orbit achieved has a period of 106.9 minutes, an apogee of 768.6 miles, and a perigee of 586.1 miles. The satellite was operational for 18 days, after which it failed to respond to any commands.

During the operational period, recorder/reproducer No. 3 failed to respond to the playback command after approximately 31.5 operational orbit hours, or pass 104. It remained in this state from pass 104 through pass 120, at which time it responded and played back the stored information. The same malfunction occurred at approximately 34.6 operational orbit hours, or on pass 131. Both malfunctions are believed to have been caused by the accidental running of the recorder/reproducer to the limit stops.

The satellite failed to respond to any commands after orbit 228, or approximately 430 hours after launch, by which time it had been operationally employed for approximately 73.5 hours. The figures used in the reliability-versus-complexity plots are operational orbit hours.

The solar power subsystem and an acquisition transmitter appeared to be working properly after 4992 operational orbit hours on April 30, 1961.

5.3 Configuration

The COURIER Satellite consists of five subsystems, each of. which is described briefly below.

1) Acquisition Access and Command Subsystem - The electronic units which make up this subsystem are the two VHF acquisition or beacon transmitters, the two VHF receivers, the code tape readers, and the command decoder. The acquisition transmitter is selected during the operational period and remains in use until the next access command turns off the VHF beacon. The VHF receivers receive the initial command and the control pilot tone. The command decoder, together with the code tape recorder, verify the commands and control the operations of the other functions within the satellite.

2) Microwave Communications Subsystem - The microwave communications subsystem contains four microwave transmitters used in pairs for frequency diversity, four microwave receivers used in active redundancy, a baseband combiner to combine the signal outputs of the receivers, and compensaters for the varying signal-to-noise ratios. The recorder/reproducers receive information for delayed relay. There are five recorder/reproducers provided--four digital types and one analog type.

3) Telemetry Subsystem - The telemetry subsystem consists of two telemetry transmitters, selected for use by appropriate command, and the telemetry generator which combines the sensor data and the command verification information and supplies these signals to the transmitter.

4) Primary Power Subsystem - This subsystem contains the solar spheres which provide the power during sunlight for operation and recharging of the batteries; two nickel-cadmium batteries; and a power control and distribution network.

5) Antenna and Diplexer Subsystem - This subsystem consists of two microwave antennas, four VHF antennas, two VHF power dividers, two microwave diplexers, and one VHF diplexer. No analysis has been made of this subsystem as the parts lists, drawings, and other data were not made available to ARINC Research Corporation during this study.

5.4 Evaluation of COURIER IB

In this evaluation, the system is divided into operational functions, some of which are dependent on prior satisfactory accomplishment of another operational function-- i.e., the operational function for real-time relay is dependent upon satellite acquisition and access to turn on the microwave communications links. For this analysis eight operational functions are considered to cover the complete operational characteristics of the satellite:

1) Acquisition (Beacon) Function

2) Access/Command and Tracking Function

3) Microwave Operation - Real Time Relay Function

4) Microwave Operation - Record (Digital) Function

5) Microwave Operation - Record (Analog) Function

6) Microwave Operation - Reproduce (Digital) Function

7) Microwave Operation - Reproduce (Analog) Function

8) VHF Telemetry Function

Contained in Table 6 are the ARINC Research Corporation calculated times to malfunction, the number of active element groups, and the observed or censored data time for each of these operational functions. The reliability-versus-complexity plot for the COURIER IB Satellite is shown in Figure 6.

TABLE 6

COURIER IB: CALCULATED AND OBSERVED DATA

| Operational Function	Number of Active Element Groups	Calculated Hours to Malfunction		Operational Orbit Hours to Functional Failure	Operational Orbit Hours to 1st Malfunction	Operational Orbit Hours to 2nd Malfunction	Operational Orbit Hours to Censoring
		AEG (L)	AEG (M)				
(1) Acquisition (Beacon) Function	4	58139.5	40983.6				4992.0
(2) Access/Command and Tracking Function	620	269.0	189.8	73.5			
(3) Microwave Operation – Real Time Function	695	258.5	181.3				73.5
(4) Microwave Operation – Record (Digital) Function	623	298.6	211.2				73.5
(5) Microwave Operation – Record (Analog) Function	617	295.3	208.7				73.5
(6) Microwave Operation – Reproduce (Digital) Function	715	255.3	179.1		31.5	34.6	73.5
(7) Microwave Operation – Reproduce (Analog) Function	710	251.9	176.6				73.5
(8) VHF Telemetry Function	620	269.0	189.8				73.5
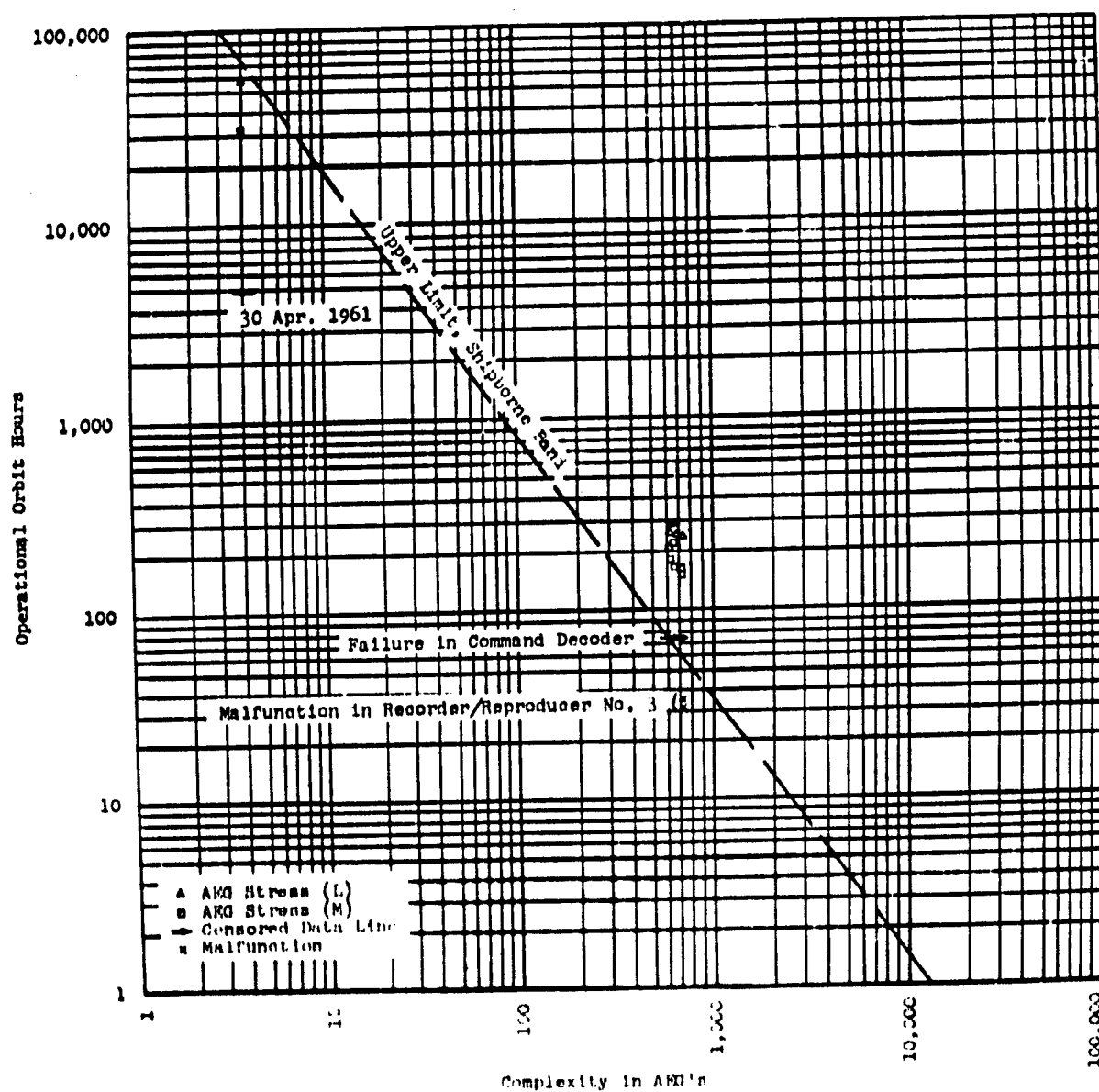
FIGURE 6

COURIER 1B: CALCULATED AND OBSERVED RELIABILITY VS. COMPLEXITY

6. TENTATIVE CONCLUSIONS

It is not intended that formal conclusions be drawn at this point in the project life. The conclusions enumerated here are really trends which this early analysis has shown to be present. The trends may change with continued monitoring of those satellites which are still active and the analysis of others. There are, at present, two important trends, both of which will be briefly discussed.

The first is the consistency with which the predicted or calculated times to malfunction are more pessimistic than the observed values. This difference, while varying in each case, usually is between a half and a full order of magnitude. Another way to say this is that the observed satellite performance is better than the predicted performance by 5 to 10 times. Several things may be contributing to this difference. The most apparent are the complete removal of the human element from the in-orbit system, the acceptance of some degradation without removal of the system for repairs, and improvements in design techniques or part reliability by a change in the state-of-the-art.

The second trend is the apparent slope of an eye-estimated line through the observed data plots. This slope is greater than that shown by the upper limit of the shipborne band. This trend may, however, be changed as more satellites with complexities in excess of 500 active element groups per operational function are evaluated and monitored under this contract.

Further conclusions and a more detailed discussion of them will be presented in the final report.

7. FUTURE WORK

It is proposed that the following additional satellites be evaluated under this contract:

1) EXPLORER VIII
2) EXPLORER XI
3) TIROS II
4) TIROS III
5) Satellite S-3

These satellites were chosen after a discussion with personnel of the National Aeronautics and Space Administration in Washington and of Goddard Space Flight Center, Maryland. The future evaluations will be similar to those described here. The details of the malfunctions and the part life hours in the space environment will be used in an attempt to revise the failure rates currently being used in satellite predictions. Monitoring of the still-operational systems described by this report will continue.

The final report will contain a composite plot of the observed data from all of the satellite studies and a fitted curve to represent the reliability-versus-complexity satellite spectrum band.